Multi period, multi blend optimization: an application to oil refining industry

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Outline

- Problem statement
- Single and multi blend optimization
- Multi period multi blend optimization
- Sources of uncertainty
- Robust optimization and its adequacy to industrial expectations
- Robust optimization: a practical definition
Optimization perimeter

Petroleum refining is a very complex production system. Its optimization as a whole is not realistic. The following decomposition is necessary.

- **Stage 1**: includes the arrival of the crude-oil marine vessels, unloading the crude-oils in the storage tanks, then mixing them into the charging tanks before being sent into the crude distillation units.

- **Stage 2**: includes all the production units in the refinery, from the crude distillation units to the intermediate stock tanks.

- **Stage 3**: includes units which blend the intermediate components and prepare the finished products (quantities & qualities) which will be conducted to their final destinations.
Final products blending problem

- 3 stage problem:
  - Component tanks
  - Blenders
  - Product tanks

- Component tanks:
  - Unit inflows (volume, properties)
  - Blend outflows (volume, properties)
  - Capacity limitations

- Blenders:
  - Component inflows (hydraulic configuration, volume, properties)
  - Product outflows (volume, properties)
  - Flowrate limitations

- Product tanks:
  - Blend inflows (volume, properties)
  - Export outflows (volume)
  - Property specifications
  - Capacity limitations
Single-blend optimization

- A single-blend optimization tool: to find out quickly an optimal blending pattern for a single finished product.
  - Integrated to the refinery simulation tool Aspen Orion
  - Complete user interface
  - Automatic handling of blending data

Advantages for refinery operators:
- Automatic recipe optimization taking into account components properties and availabilities

Main limitations:
- What should be the optimization criterion?
  - Optimize property giveaways or component values
  - No consideration of future blends
    - The user needs to adjust the optimal solution according to his future blending plans
- Taking into account the number of components (n) and the quality restrictions (m), and n > m, at each single-blend optimization, (n-m) of components are set to zero!
Multi-blend optimization

- Multi-blend optimization is an extension of single-blend optimization
- 3 main reasons for multi-blend optimization
  
  - Generates optimized recipes and allocates hydraulic resources (pumps) for the first blend and future blends
    → the optimal pattern is directly useful for the operators
  
  - Manages the stocks on a long-run period (an horizon of 2 to 3 weeks)
  
  - Makes arbitrage between purchase and sale of intermediate and finished products
Multi-blend optimization

Most of the refineries follow the same organization model

The production lines of gasoline/diesel/fuel oils are managed independently.

The production line manager has 2 interlocutor: short-run and long-run operations.

Is the refinery able to produce 30 Kt of gasoline 98 in 15 days?

What should be the recipe of the gasoline 95 to be started at 15 pm?
Multi-blend optimization model

**Given the following input data:**
- set of component tanks (i.e. isomerate, reformate, ...)
- set of final product tanks (i.e. SP95, SP98, US regular, ...)
- set of properties (i.e. MON, RON, sulfur content, ...)
- initial tank inventories (quantity and quality of products in each tank)
- component tank inflows over time (quantity and quality of products sent into the tank)
- final product lifts and exports (date and quantity)
- schedule of blends defined by a final product tank and a start time (*might be fixed a priori*)

**Select the following decisions:**
- amount of final products to be blended during each blend
- blend recipes (proportion of each component to be used in the blend)
- pump allocation to component tanks

**while satisfying the following constraints:**
- tank capacity limitations
- final product specifications
- pump allocation constraints
  - at most one pump allocated to a given component tank
  - at most one component tank allocated to a given pump
- hydraulic constraints (i.e. pumps and blender flowrate limitations).

**With an objective function of**
- Maximizing the gross margin (products value – component costs) or minimizing a give away cost
Multi-blend optimization model

- **Linear constraints**
  - Material balance for components & products
  - Storage capacity for components & products

- **Non-Linear constraints**
  - Nonlinear blending laws
  - Blend property calculations in tank heel (if qualities in tanks remain stable, then the model is almost linear with respect to the property blends)

- **Discrete variables**
  - Pump allocation decisions

Therefore, the multi-blend optimization is a **Mixed Integer Non Linear Program (MINLP)**.
- Almost 100 discrete variables, 100 continuous variables and 100 constraints.
Multi-period multi-blend

In essence, the multi-Blend optimisation problem is a multi-period problem, since it is about optimal allocation of resources (components) available in each period to the blends planned in the same period.

However, it is worth looking a little further into some aspects of the problem which introduce additional complexity, namely:

- Process units operations dynamics
- Component qualities dynamics
Multi-period multi-blend

- Process units operations are not necessarily synchronised with blend operations, i.e. feed qualities and operating parameters follow « their own calendars »

- Units rundown qualities and quantities evolution follows the same calendars as their originating process units

- Consequently, component tanks dynamics are not synchronised with blend operations, in addition, their qualities are also variables of the optimisation problem due to the mixing of incoming steams with tank heels
Multi-period multi-blend

- Multi-period multi blend optimisation is more than just allocating components with static qualities to the right blends.

- It is about the optimal utilisation of several parallel (and potentially asynchronous) dynamics, and dealing with the inherent uncertainties.
Sources of uncertainty

- Component qualities and quantities are predicted by simulation systems, which have their own inaccuracies.

- Tank qualities are calculated using blending laws which are empirical and imperfect.

- Finished products quantities may be subject to uncertainty.

- Unforeseen events which can disrupt units operations.
Robust optimisation adequacy to industrial expectations

- The Max-Min approach is too rigid and misses real optimisation targets

- Chance constraints (expressed in terms of the probability of meeting constraints) are not sufficient in practice. Ex: if a quality specification is not met, the product cannot be delivered

- The assumption that adjustable variables are affine functions of random parameters is too restrictive and may not be applicable due to non-linear blending laws
Robust solutions: A practical definition

Feasibility:

- The solution calculated must remain feasible for all possible realisations of the uncertain parameters (this is similar to the stochastic programming requirement)

- If not, it should be possible to recover feasibility with a low penalty
Robust solutions: A practical definition

- Optimality and incremental adjustments
  - It must be possible to calculate an upper bound of the distance to the “a posteriori” optimal objective function (the one calculated once all uncertainties lifted)
  - It should be possible to progressively adjust some decisions once some random parameters reveal themselves
  - A near optimal adjusted solution should be possible to construct in the neighbourhood of the initial solution